InSb Bipolar Transistors Operating at Room Temperature

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Outline

- Why InSb?
- Carrier Exclusion/Extraction
- Bipolar Devices
  - Experimental Results
  - Modelled Results
- Conclusions

Why InSb?

	Silicon	GaAs	$In_{0.53}Ga_{0.47}As$	InAs	InSb	units
Energy gap	1.12	1.43	0.75	0.356	0.175	eV
Electron effective mass	0.19	0.072	0.041	0.027	0.013	
Electron mobility	1,500	8,500	14,000	25,000	78,000	$cm^2\ V^{-1}\ s^{-1}$
Electron saturation vel^y	1.0×10^7	1.2×10^7	8×10^6	3×10^7	5×10^7	$cm\ s^{-1}$
Electron mean free path length	0.07	0.15	0.19	0.27	0.58	μm
Intrinsic carrier conc^n	1.6×10^{10}	1.1×10^7	5×10^{11}	1.3×10^{15}	1.9×10^{16}	cm^{-3}

Special Properties of InSb

- High mobility $\Rightarrow$
  - low operating voltage
  - low power dissipation
- High electron velocity $\Rightarrow$
  - high speed
  - high gain
  - low noise
- High mean-free path $\Rightarrow$
  - large ballistic effect
  - high speed

Consequences of Special Properties

- Cut-off frequency is much higher than other technologies for the same sized device
  - Can process more information per second than any other technology
- Low operating voltages and high gain per unit current offer very low power consumption
  - Can process more information per Watt than any other technology

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Problem

- High intrinsic carrier concentration
  - large number of minority carriers in active region
- Large off-state leakage current in transistors
  - Parasitic bipolar action in FETs
- Increased breakdown and poor voltage gain

Solution

- Use carrier exclusion/extraction (subject to several QinetiQ patents) to reduce carrier concentration in active region
  - Reverse-biassed heterostructure substrate contact to active region in FETs
  - Excluding base contact in bipolars
- Resulting devices operate successfully at room temperature
    - Greatly reduced leakage
    - Greatly reduced breakdown

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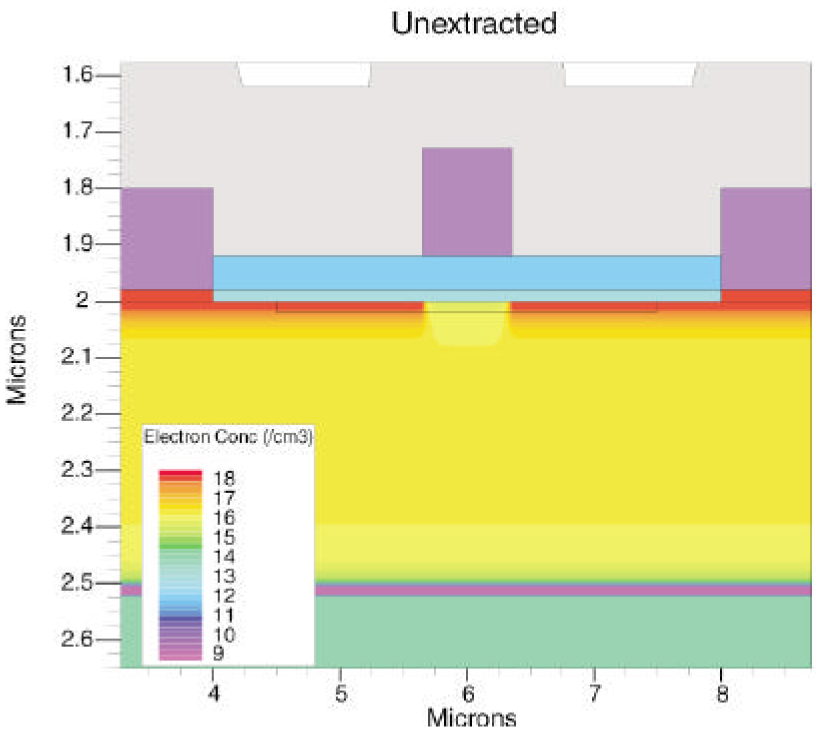
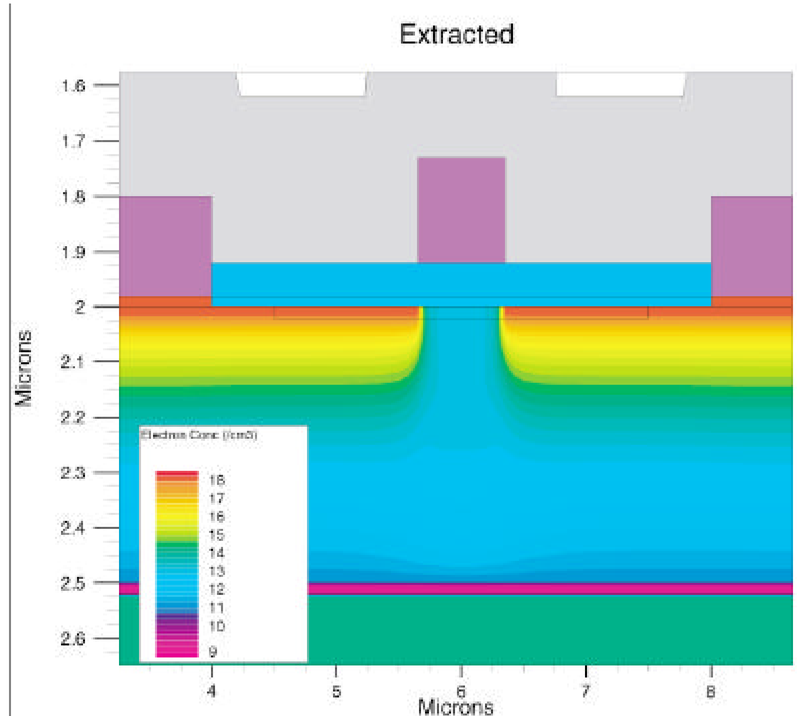
Modelled FET Example

Without substrate bias



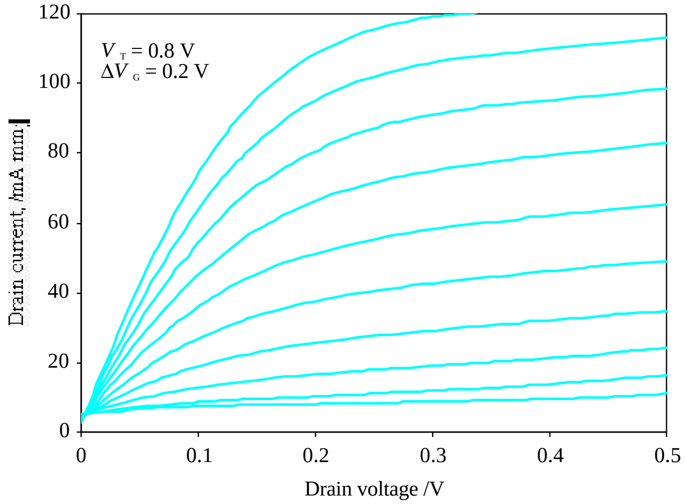
With substrate bias

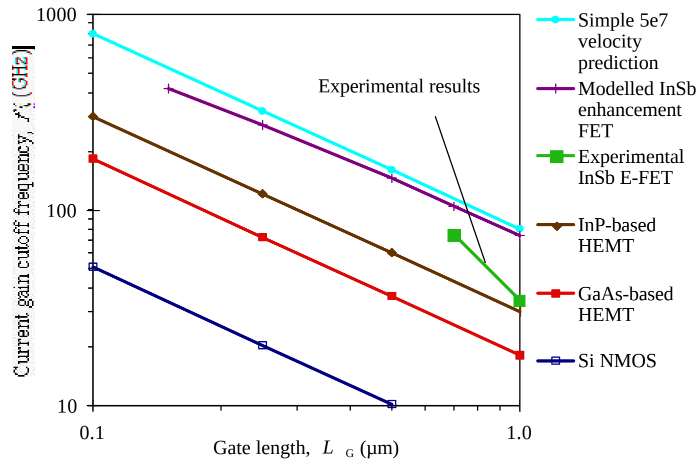


Substrate bias reduces carrier concentration in active region

InSb FETs

- Demonstrated InSb FETs previously*
- Showed good DC performance, with good turnoff
- Showed excellent AC performance, with record f_T reported for gate length of 0.7 µm

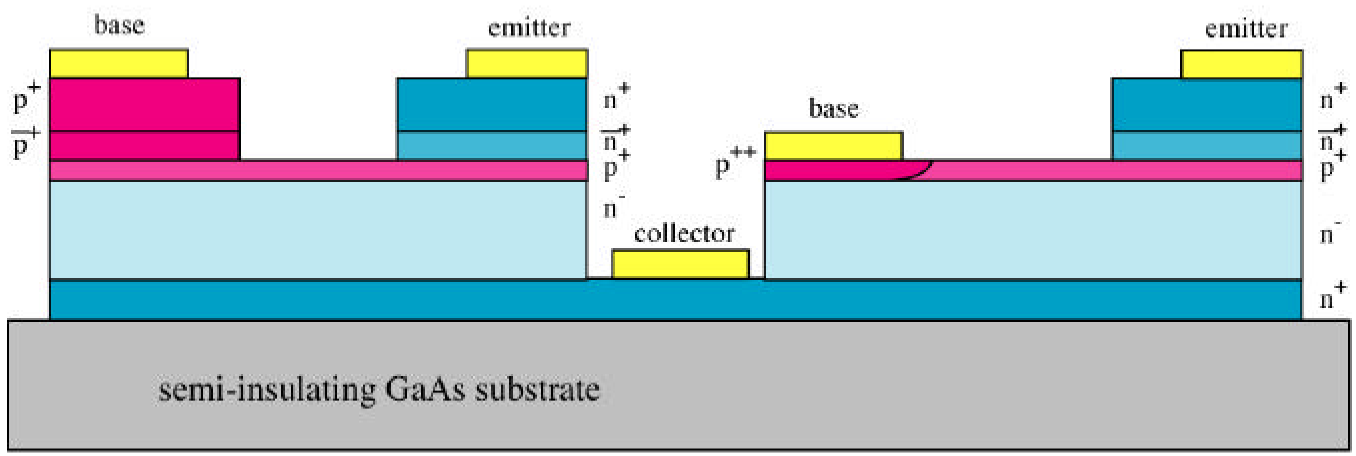




*Ashley, Dean, Elliott, Khaleque and Phillips, IEDM 1997, 751

Bipolar Devices

- Use excluding base contact (heterostructure or homostructure), which can be reverse-biassed to give good off-state leakage
- Otherwise works just like a conventional HBT
- Subject to QinetiQ patent*



***Phillips, UK Patent Application No. 0012925.4**

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Bipolar Device - Test Structure

- Made initial structure to test room temperature operation
- Does not contain base implant at present
- Larger off state leakage in agreement with model
    - Predicted to be reduced by factor of 8 using implant
- Good performance otherwise
- Reverse-biassing base suppresses impact ionisation - increasing off-state breakdown voltage

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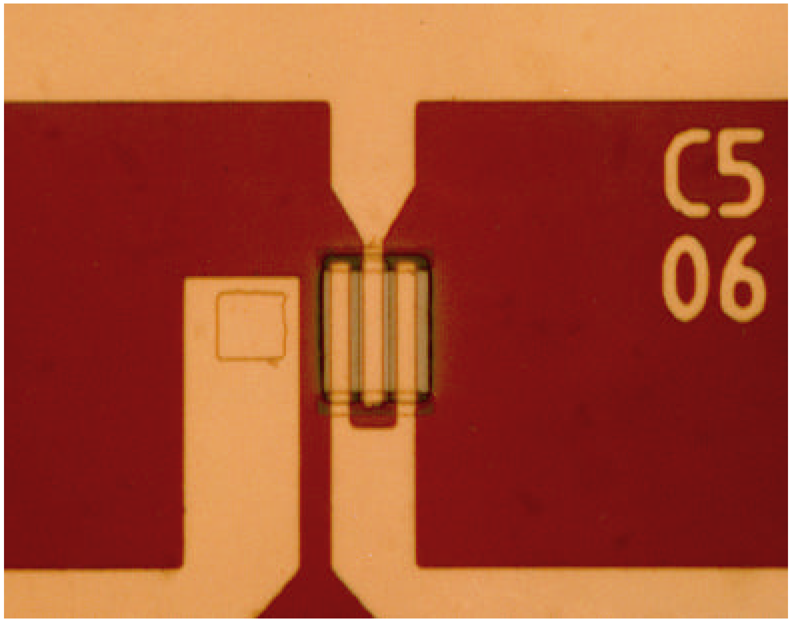
Growth and Fabrication

- Layer growth by MBE on (100) InSb substrate
  - Si and Be as *n*- and *p*-type dopants
- Device mesa 25 µm wide
- Emitter width 6 µm, collector width 18 µm
- Sputtered Cr/Au contacts (not optimised for AC)



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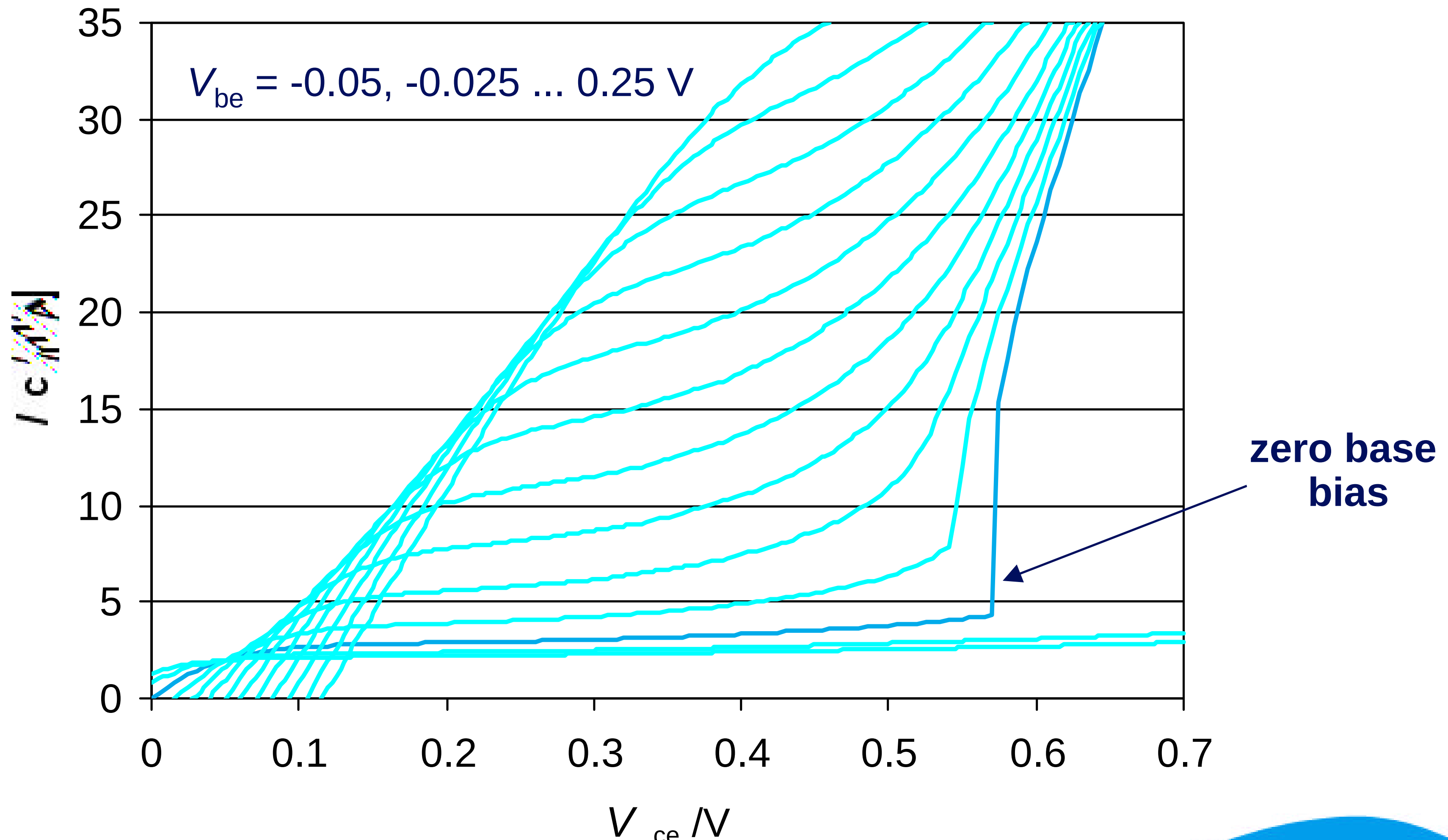
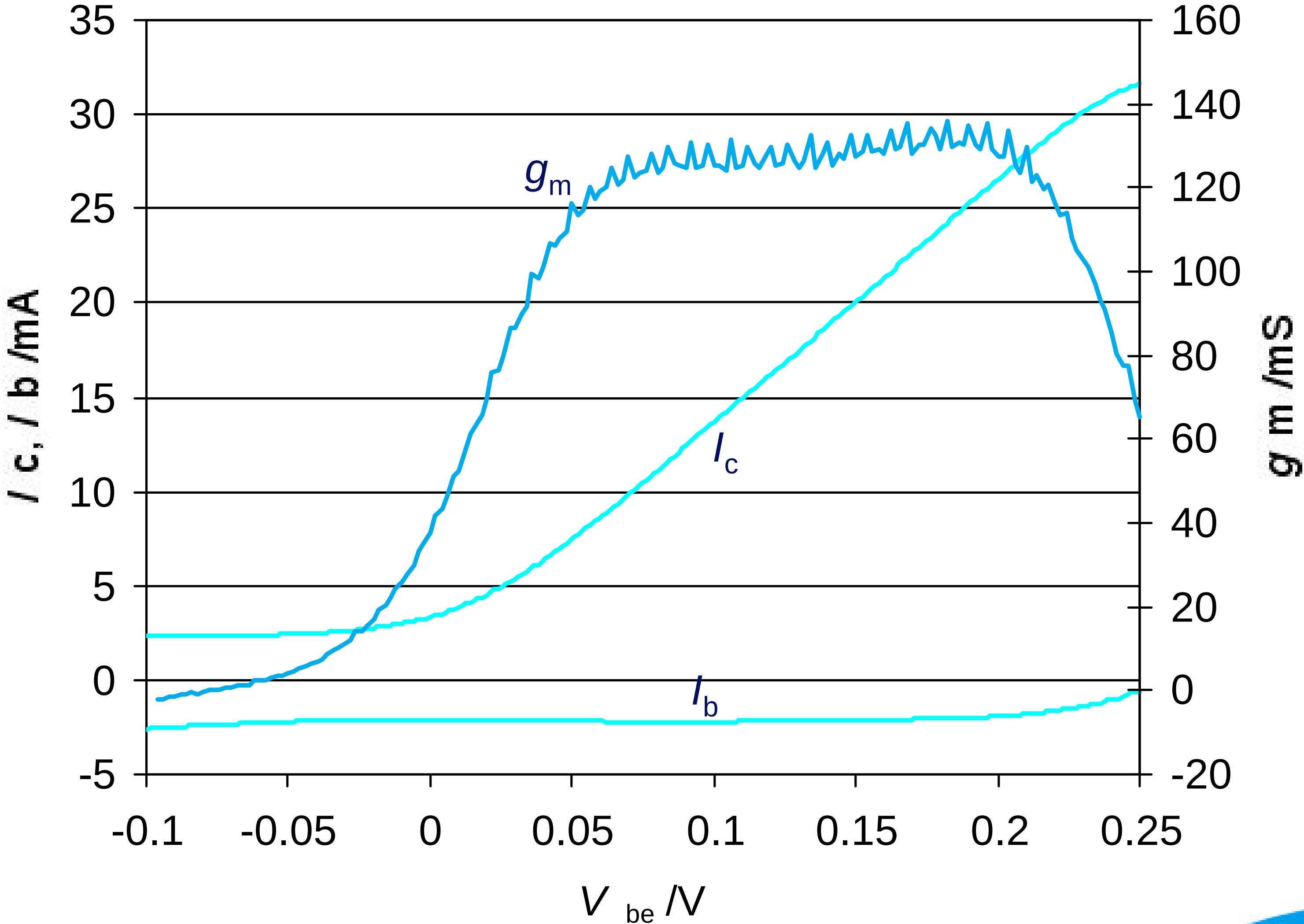
6 µm Emitter InSb HBT - Output



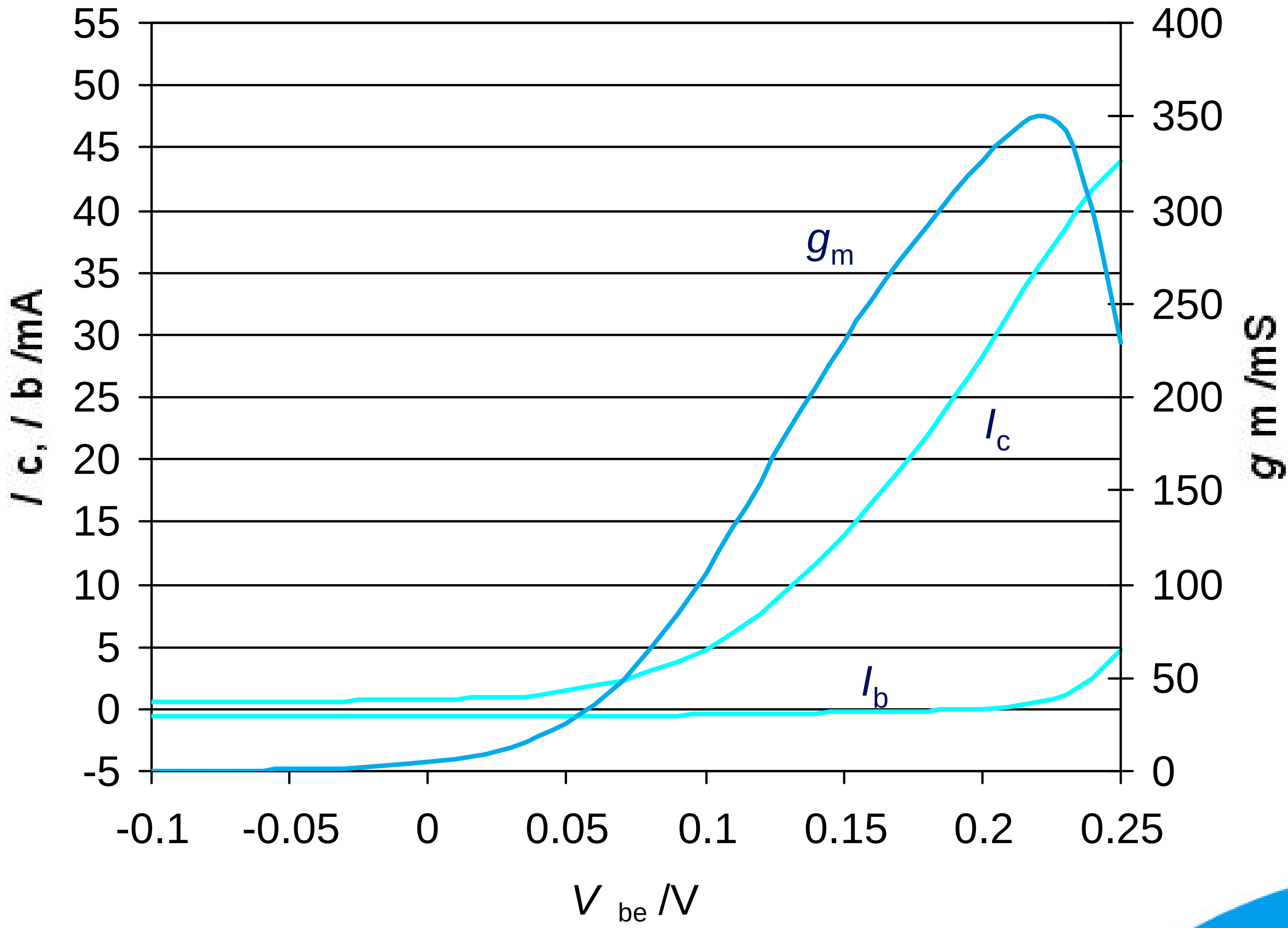
Darker line is zero base bias - negative bias reduces breakdown

6 µm Emitter InSb HBT - Transfer



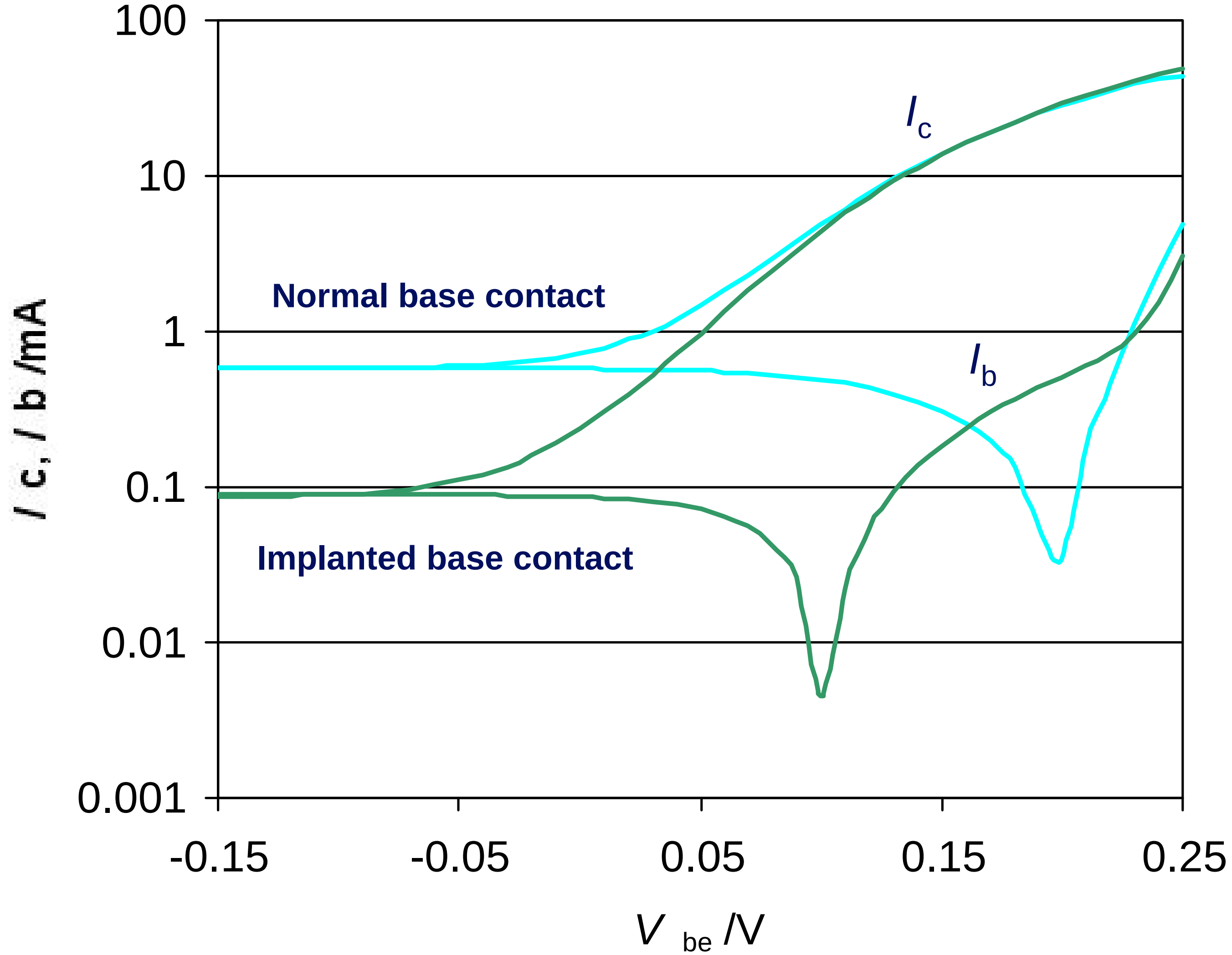
Base current negative and fairly constant - very high current gain

InSb HBT Model - Transfer



Negative base current effect seen in model as well

InSb HBT Model - Gummel



Implant reduces leakage current

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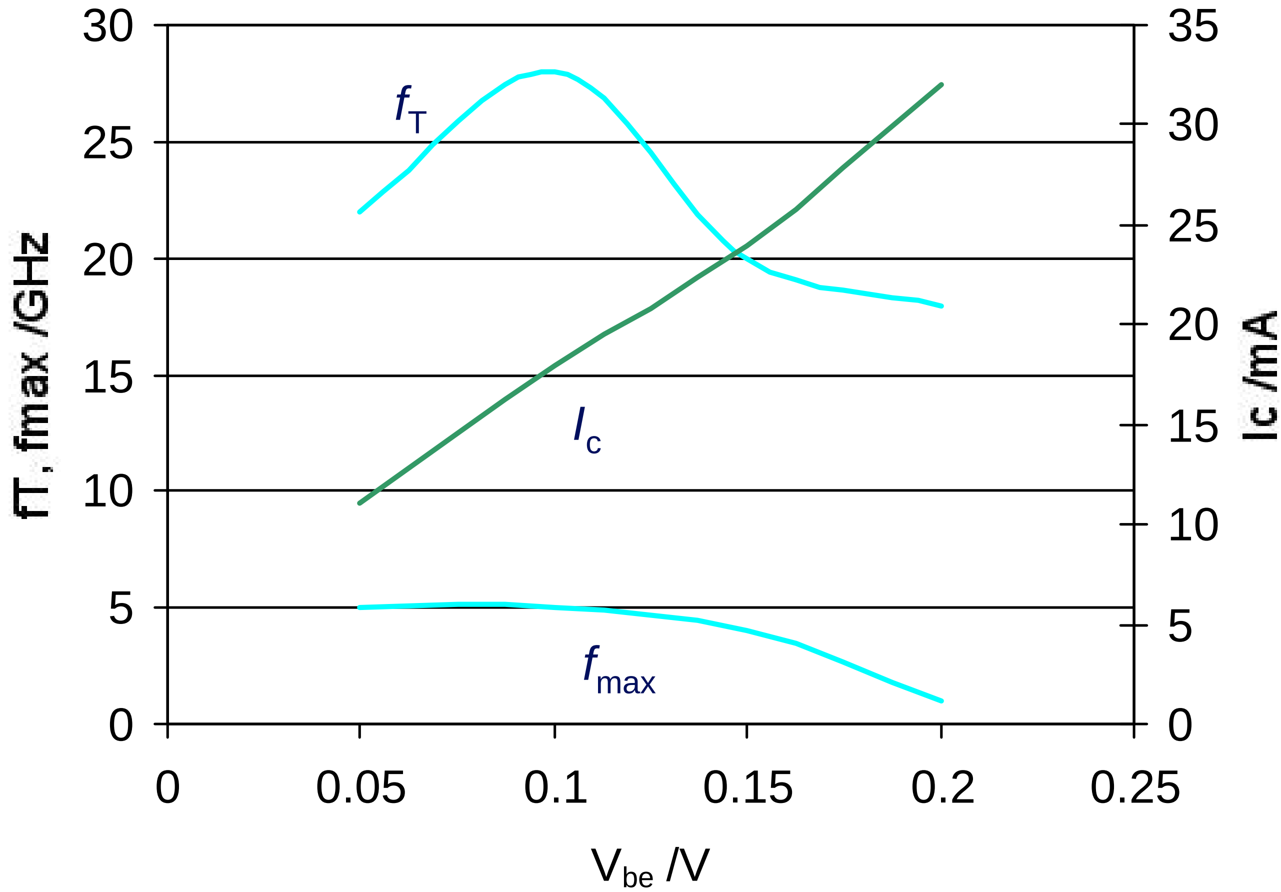
InSb HBT - AC data



Bond pads not optimised for AC

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Bipolar Devices

- Complete device design not yet fabricated, but promises excellent performance
  - Ultra high transconductance
  - Very high voltage gain
  - Same low voltage operation as FETs
  - f_T > 800 GHz, f_{max} > 200 GHz, 1 µm emitter
- Suitable for digital, medium power or ADCs
- Potentially highly manufacturable process with high uniformity
- Potential for ultra-low noise
- Make DHBT for higher breakdown voltage

Possible Applications

- Electronic components for high-speed optical comms
    - 160 GB/s generation
- Interface with superconductors
    - Niche at present but could become large
    - Need very low voltages and low noise, plus cryogenic capability
- Possible interface with 2D IR arrays
- High speed digital processing
- There will always be uses for higher speed and lower power electronics